Amendments to the Specification:

Please replace the Specification of the present application, including the Abstract, with the following Substitute Specification. A marked-up version of the Substitute Specification and Abstract is attached hereto.

SPECIFICATION

TITLE OF THE INVENTION

METHOD AND TRANSMISSION DEVICE FOR TRANSMISSION OF DATA IN A MULTI-CARRIER SYSTEM

BACKGROUND OF THE INVENTION

[0001] In Orthogonal Frequency Division Multiplexing OFDM, which is used particularly in WLAN radio networks, such as those functioning in accordance with the IEEE 802.11 Standard as well as for HiperLAN, a method is used in which simultaneously a number of carrier frequencies, also simply referred to as carriers, are employed for the transmission of a digital signal. However, these carrier frequencies are only modulated with a reduced transmission rate in relation to the overall transmission rate available (across all carriers).

[0002] For this purpose, the frequency band available for OFDM is subdivided into a number of (sub)carrier bands. The carrier frequency spacing is governed by the transmission rates.

[0003] An OFDMA-based access scenario in a system with a number of users (Multiple User system) is based on the approach of assigning each of the users their own OFDM sub-carrier.

[0004] In a system of this type and under real transmission conditions crosstalk effects between the carriers arise, also referred to as ICI (Inter-Channel Interferences).

[0005] ICI is produced in this case both as a result of a doppler shift arising from the movement of mobile terminals and also as a result of an oscillator phase noise.

[0006] In an OFDM system, the so-called "downlink," which in mobile communications generally identifies communication going from a base station to a mobile station, both the doppler shift as well as the part of the oscillator phase noise generally corrected/compensated in the receiver, which is called Common Phase Error (CPE), is the same for all carrier frequencies of the sub-carrier bands, so that for this communication direction no access problem triggered by the OFDMA principle arises.

[0007] A system and a method is known here from US 2002/0105901 A1 in which, by forming the signal waves, a manipulation of the spectrum of an OFDM signal is achieved.

[0008] From Staamoulis et al: "Space-time block codes OFDMA with linear precoding for multirate services," IEEE Transactions on Signal Processing, Jan, 2002, a system is known which eliminates a multi-user interference in an OFDMA system.

[0009] From EP 0 938 208 an OFDMA/TDMA system is known with a number of users, in which sub-carriers in edge areas of a sub-carrier band are not modulated, in order to eliminate interference on adjoining frequency slots.

[0010] In the "uplink," a term generally used in mobile communication to designate the communication going in the opposite direction, from a mobile station to a base station, the problem arises of the doppler shifts not being constant over all sub-carriers as a result of the different relative speeds of the mobile subscribers. In addition, the phase noise or the correctable part of the phase noise for this communication direction is uncorrelated as a rule since it is predominantly generated by the unsynchronized oscillators of the individual users.

[0011] The Inter Channel Interference produced by the doppler shift as well as the phase noise with his/her communication direction represents, in an OFDMA-based uplink a limitation of the transmission characteristics which can go as far as resulting in a complete failure of the system.

[0012] Accordingly, the present invention seeks to specify a method as well as an arrangement which make possible an essentially interference-free OFDMA access in the uplink.

SUMMARY OF THE INVENTION

[0013] An advantage of the method in accordance with the present invention it is that a reduction which extends as far as elimination of the ICI through send-side pre-emphasis of the send signal for a part of the carrier frequencies of the sub-carrier band as a function of the current transmission facilities is achieved, since in this way the limitations of the transmission characteristics in this communication direction are removed or reduced, with the

pre-emphasis relating to all or any of the sub-carriers at the edges of a frequency band which is assigned to a user and as a result has the advantage that precisely those sub-carriers of a user are pre-emphasized which contribute significantly to ICI, regardless of whether phase noise or doppler shifting is the aspect limiting the system.

[0014] Preferably, the signal is pre-emphasized with the aid of the filter by a signal filter which corresponds in the time range to a windowing and, thus, in the frequency range to a folding and is particularly identified by the fact that the filtered sub-carriers feature high rates of change and thereby make a significant contribution to ICI suppression. In addition, a receiver which is used in a system employing the inventive method needs only slight modification or no modification at all to achieve this. Filtering the sub-carriers in the edge area of an OFDM symbol also allows the guard band (i.e., the number of the unused sub-carriers at the edge of the OFDM symbol) to be reduced so that, in addition, a comparatively higher data rate can be achieved.

[0015] It is advantageous to execute the pre-emphasis such that the value of a first symbol duration assigned to the emphasized carrier frequencies remains the same. In particular, the time that range windowing or the folding operation in the frequency range is identified by the fact that the length of the time range window $\omega_{(k)}$ overall does not exceed the OFDM useful symbol duration and duration of the cyclic prefix and the required rate of change of the sub-carriers is essentially determined by the oversampling.

[0016] Preferably, the length of the OFDM user symbol duration is the same as the length of the time range window $\omega_{(k)}$. Basically, two different embodiments of the time range window $\omega_{(k)}$ exist: firstly windows which would fulfill the Nyquist criterion such as, for example, the Root-Raised-Cosine window (i.e., that despite send-side windowing or filtering of the receiver, especially with an ideal channel, is in a position to reconstruct the sent data error-free); secondly windows or filters which do not fulfill the Nyquist criteria in the sense given above but, however, by contrast allow comparatively higher filter rates of change and

thereby a comparatively better ICI suppression as, for example, the Blackman window.

[0017] The number of pre-emphasized sub-carriers also basically can be extended to all sub-carriers, especially when the combination of doppler effect and phase noise is the limiting factor for the ICI.

[0018] Additional features and advantages of the present invention are described in, and will be apparent from, the following Detailed Description of the Invention and the Figures.

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BRIEF DESCRIPTION OF THE FIGURES

[0020] Figure 1 shows send-side modulation of OFDM symbols in accordance with the prior art.

[0021] Figure 2 shows send-side modulation of OFDM symbols in accordance with the inventive method.

[0022] Figure 3a to 3c show diagrams of a simulation with a typical pre-emphasis function as well as a typical set of parameters.

DETAILED DESCRIPTION OF THE INVENTION

[0023] Figure 1a shows a schematic diagram of the send-side modulation method in accordance with the prior art or the structure of the transmitter to execute this known method. According to the prior art, each symbol pulse $S_{d(k)}$ of a kth carrier f_k for N sub-carriers of a symbol carrier band of the bandwidth B is modulated; i.e., for each symbol pulse $S_{d(k)}$ for a time window of length T an Inverse Fast Fourier Transformation (IFFT) in accordance with the formula

$$S_{d(k)} = \sum_{n=0}^{N-1} S_{d(n)} e^{j2\pi \frac{n}{N} k}$$

is applied and from it an OFDM symbol $S_{d(k)}$ is generated. To counteract echoes and/or synchronization errors, this OFDM symbol $S_{d(k)}$ with duration T, through which the window length of a corresponding Fourier analysis in the receiver is also provided with a guard time (i.e., the time T will be extended by a time T_g) usually

referred to as the guard time so that overall for the OFDM symbol to be sent $S_{d(k)}$ a symbol time T_s is produced.

[0024] This modulation process is executed in accordance with the prior art for all carriers f_k of a sub-carrier band with N carriers.

[0025] Figure 1b shows the filter structure IFFT underlying the known IFFT method which is produced in accordance with the formula

$$c(k) = \frac{1}{N} \cdot \sum_{n=0}^{N-1} d(n) \cdot e^{j2\pi \frac{n}{N} k}$$

[0026] The receiver-side filter structure used to reverse the FFT method is identified by the formula

$$\hat{d}(n) = \sum_{k=0}^{N-1} c(k) \cdot e^{-j2\pi \frac{k}{N} n}$$

[0027] Figure 3a shows a schematic diagram of the inventive method or structurally the essential elements of the transmitter executing the inventive method. By contrast with the procedure in accordance with the prior art in accordance with the present invention with the exception of those carriers f_n which are located in the edge area of the sub-carrier band, all symbol pulses $S_{d(k)}$ assigned on the remaining carriers f_n (i.e., all symbol pulses $S_{d(k)}$ on carriers f_n with $\kappa \in \{0; N - 1\}$, are fed to the IFFT in accordance with the prior art , whereas the symbol pulses on the carriers f_n in the edge area of the sub-carrier band (i.e., the symbol pulses $S_{d(k)}$ assigned to the carriers f_n with $k \in \{0; Nr-1\}$ are subjected to an oversampling with the rate r and pre-emphasis, with the pre-emphasis being undertaken such that the relevant symbol pulse $S_{d(k)}$ is windowed or filtered with a pre-emphasis function so that the pre-emphasis function $\omega_{(k)}$ determines the frequency response of the pre-distorted/filtered sub-carrier.

[0028] Subsequently, all symbol pulses $S_{d(k)}$ per user are modulated up to the relevant sub-carrier frequency and, as is usual in the IFFT method accordance with Figure 2a, added up.

[0029] In this case, for send-side pre-emphasis in accordance with the present invention, a typical filter structure shown Figure 2b represented by the formula

$$\tilde{c}_{(k)} = \frac{1}{N} \cdot \sum_{n=0}^{N \cdot r-1} \omega_{(k)} \cdot \tilde{d}_{(n)} \cdot e^{j2\pi \frac{n}{N \cdot r} k}$$

is employed, with the pre-emphasis being achieved through linkage with a window function ω(ν) ιν τηε τιμε αρεα συχη ασ φορ εξαμπλε α "Blackman window" with oversampling. This window function is for example described by for $n = 0, .. , M-1$ with

$$\omega_{(n)} = \left[\underbrace{\tilde{\omega}_{(n)}}_{\frac{N \cdot r}{8}}, \underbrace{0 \ldots 0}_{\frac{N \cdot 3 \cdot r}{4}}, \underbrace{\tilde{\omega}_{(n)}}_{\frac{N \cdot r}{8}}\right]$$

and,

$$\tilde{\omega}_{(n)} = 0{,}42 - 0{,}5 \cdot \cos(2\pi \frac{n}{M-1}) + 0{,}08 \cdot \cos(4\pi \frac{n}{M-1})$$

with

$$M = \frac{N \cdot r}{4}$$

preferably applying here and r giving the oversampling rate, and where the vector $\widetilde{d}_{(n)}$ is defined as a result of the oversampling in the following way

$$\widetilde{d}_{(n)} = \begin{bmatrix} d_{(n)} \\ \vdots \\ d_{(n)} \\ 0 \\ \vdots \\ 0 \end{bmatrix} \begin{matrix} \left.\begin{matrix} \\ \\ \\ \end{matrix}\right\} \forall n = [0 \ldots N-1] \\ \left.\begin{matrix} \\ \\ \\ \end{matrix}\right\} \forall n = [N \ldots N \cdot r - 1] \end{matrix}$$

[0030] Furthermore, Figure 2b shows a receive-side filter structure scaled FFT, provided to reverse the IFFT pre-emphasized by the send-side filter structure ωIFFT and described by the formula

$$\hat{d}_{(n)} = \sum_{k=0}^{N-1} \widetilde{c}_{(k)} \cdot e^{-j2\pi \frac{k}{N} n}$$

which, in a real system is essentially identical to a receiver structure in accordance with the prior art (Figure 1).

[0031] Figure 2c shows an inventive OFDMA structure in the uplink, with 2 different users (namely, User A and User B) using different sub-carrier frequency bands and where in accordance with the present invention preferably on the adjacent sub-carrier L of the first user (User A) and on the sub-carrier (L+1) of the second user (User B) the pre-emphasis is applied in order to suppress the ICI in the base station.

[0032] In Figures 3a and 3b, to illustrate the results of the calculation with the formulae mentioned above, illustrative diagrams with the following parameter sets

N	=	2	4	8	16	32	64
r	=	512	256	128	64	32	16
M	=	512	512	512	512	512	512

are shown.

[0033] In Figure 3a, the power density spectrum of a non-ideal oscillator, the combined power density spectrum of a non-ideal transmit oscillator and of a non-ideal receive oscillator can be seen, which will be examined as representative of a time-variant fault which causes ICI. In addition, Figure 3 shows a sub-carrier in accordance with the prior art (solid line) and a filtered sub-carrier in accordance with the invention (solid line marked with circles). It can be seen from this diagram that even with a folding in the frequency range of sub-carrier and power density spectrum of the fault, the resulting power density spectrum emits far less energy outside the frequency band assigned to a sub-carrier in each case and thereby comparatively less ICI.

[0034] Figure 3b shows quantitatively how much ICI the sub-carrier windowed with a Blackman window generates by comparison with a sub-carrier in accordance with the prior art, with the combined reference power density spectrum of transmit and receive oscillator in accordance with Figure 3 having been used as the power density spectrum of the fault.

[0035] Although the present invention has been described with reference to specific embodiments, those of skill in the art will recognize that changes may be made thereto without departing from the spirit and scope of the present invention as set forth in the hereafter appended claims.